

VANDERBILT UNIVERSITY



School of Engineering

High-Speed Single-Event Current Transient Measurements in SiGe HBTs

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Acknowledgements...



- **NASA Electronic Parts and Packaging program**
- **NASA Advanced Avionics Processor and Systems Project**
- **DTRA Radiation Hardened Microelectronics program under IACROs #08-4343I and #09-4587I to NASA**
- **AFOSR MURI program and DURIP award**
- **SiGe teams at the Georgia Electronic Design Center and IBM**
- **Naval Research Laboratory**
- **Sandia National Laboratories**
- **CEA, DAM, DIF (Arpajon, France)**

Overview

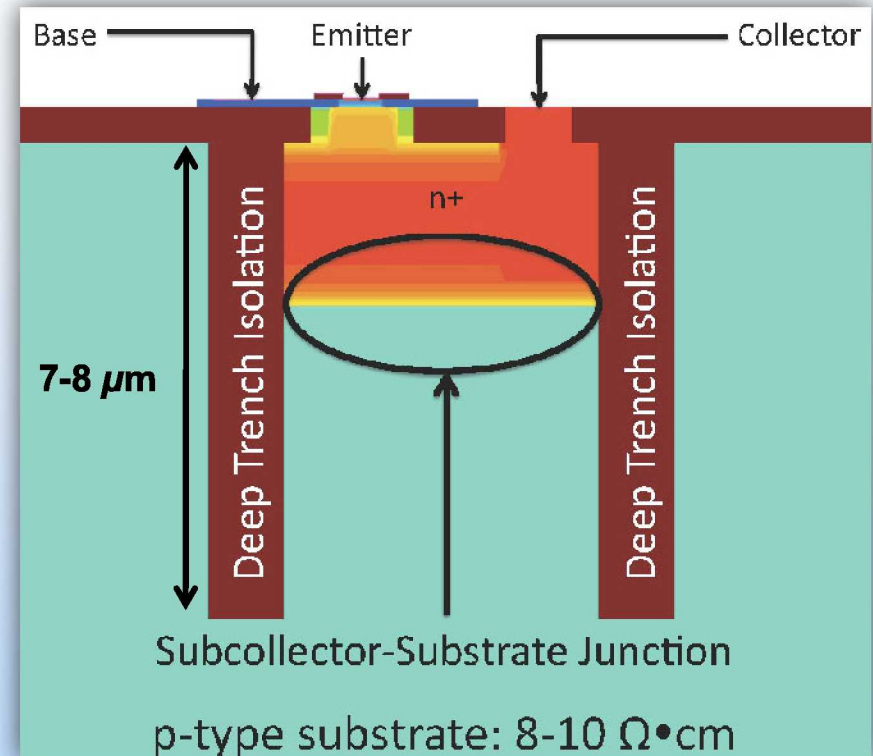


- **IBM 5AM SiGe HBT device background...briefly**
- **High-speed measurement setup**
 - Heavy ion microbeam, heavy ion broadbeam, pulsed laser
 - Advantages/disadvantages
- **Low-impedance current transient measurements**
- **Understanding what the transients represent for single-event effects in SiGe HBTs**

Device Background and Introduction



IBM 5AM SiGe HBT ($0.5\ \mu\text{m}$)



J. A. Pellish *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

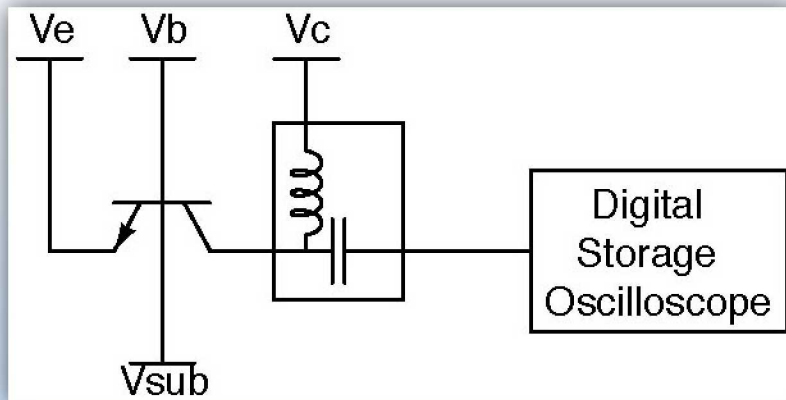
- **Key device characteristics**
 - Deep trench isolation
 - Subcollector junction
 - Lightly-doped p-type substrate (large)
- **Extend state-of-the-art knowledge**

Previous tests focused on pulsed laser carrier generation only
New tests focus on heavy ion carrier generation

Microbeam Experimental Setup



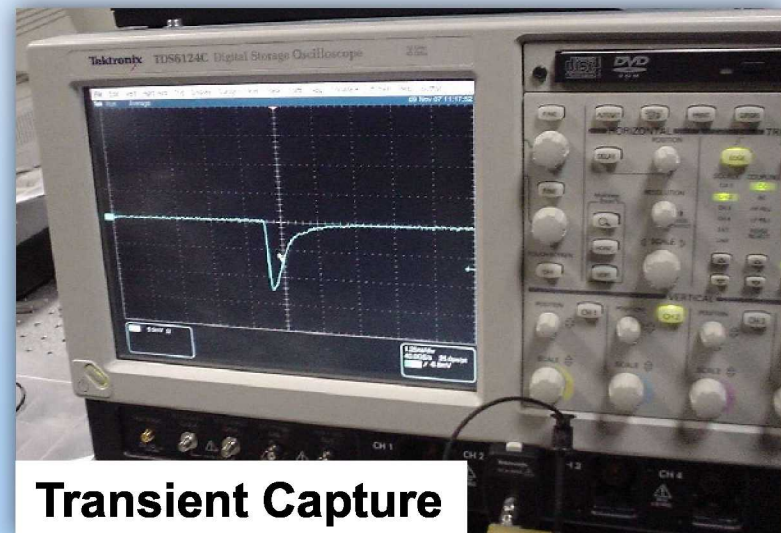
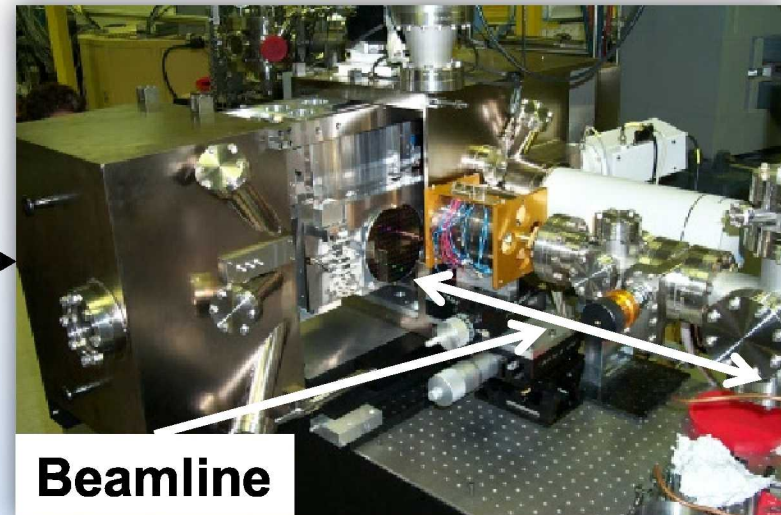
General electrical setup used in all cases



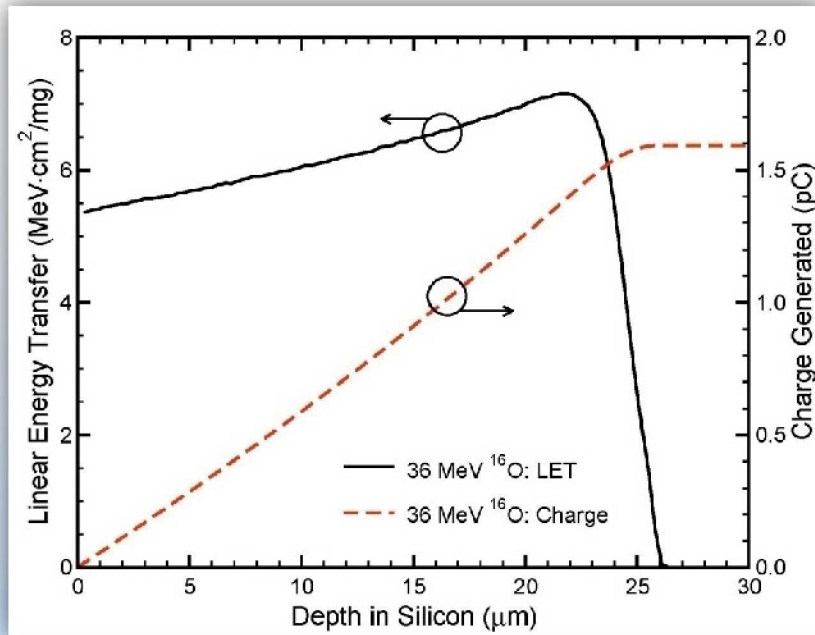
Similar setup for 4-terminal measurements

- PSPL Bias Tees: 5542K
- DPO/DSO: Tek 71604A (16 GHz; 50 GS/s), Tek 72004A (20 GHz; 50 GS/s)
- 2.9 mm coaxial cable assemblies (40 GHz)

Sandia National Laboratories' Microbeam Chamber



Microbeam Experimental Setup

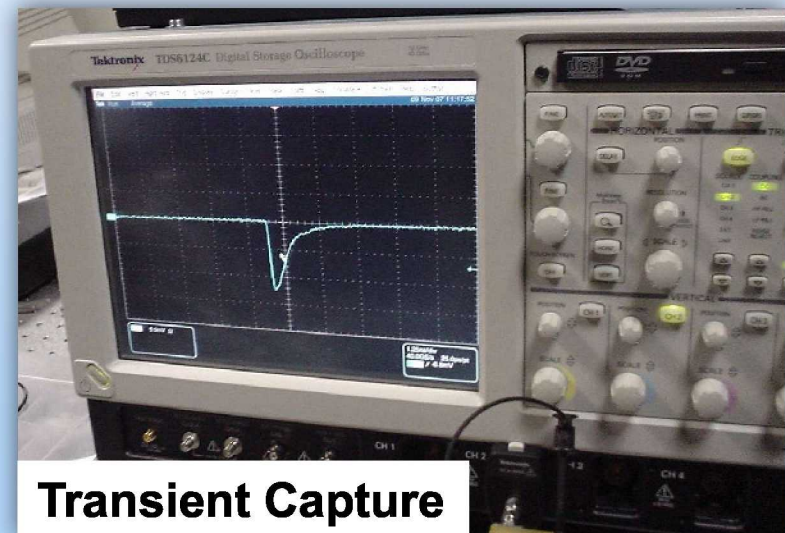
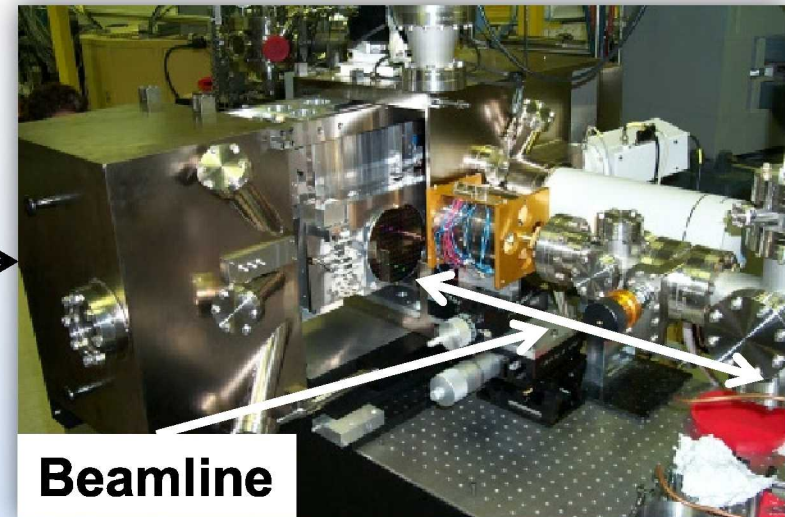


36 MeV ¹⁶O dE/dx profile

[SRIM-2008]

**Sandia National Laboratories'
Microbeam Chamber**

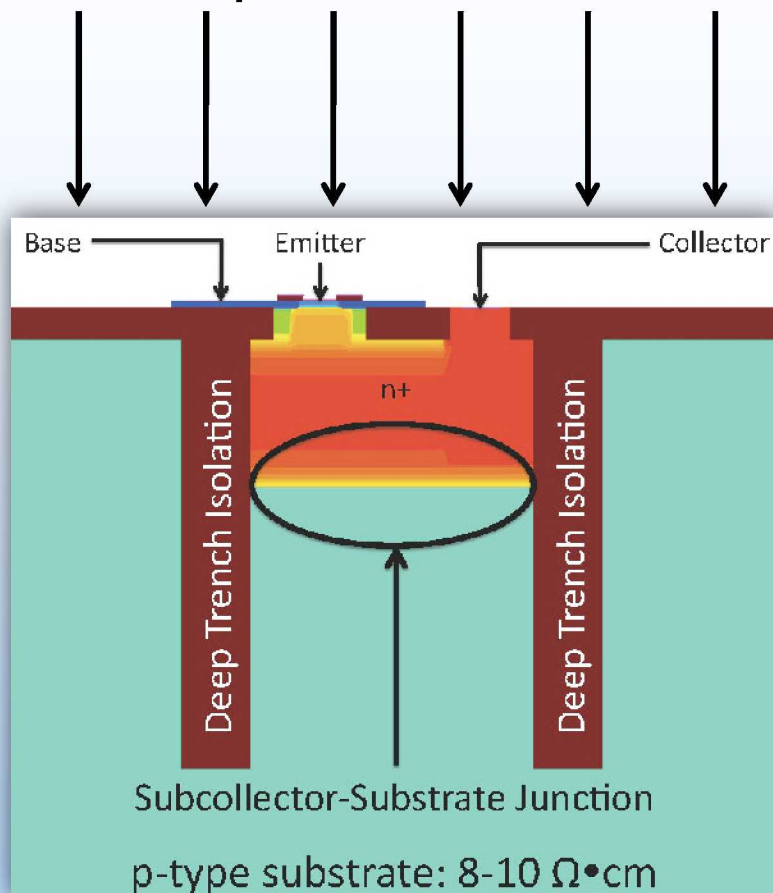
****Advantages/Disadvantages****



Heavy Ion Broadbeam Experiments



No position correlation



University of Jyväskylä
K-130 Cyclotron



****Advantages/Disadvantages****

- Data collection at the University of Jyväskylä, Finland and GANIL, France
- 9.3 MeV/u cocktail including ^{20}Ne , ^{40}Ar , ^{82}Kr , and ^{131}Xe and 45.5 MeV/u ^{136}Xe

Two-Photon Absorption Testing

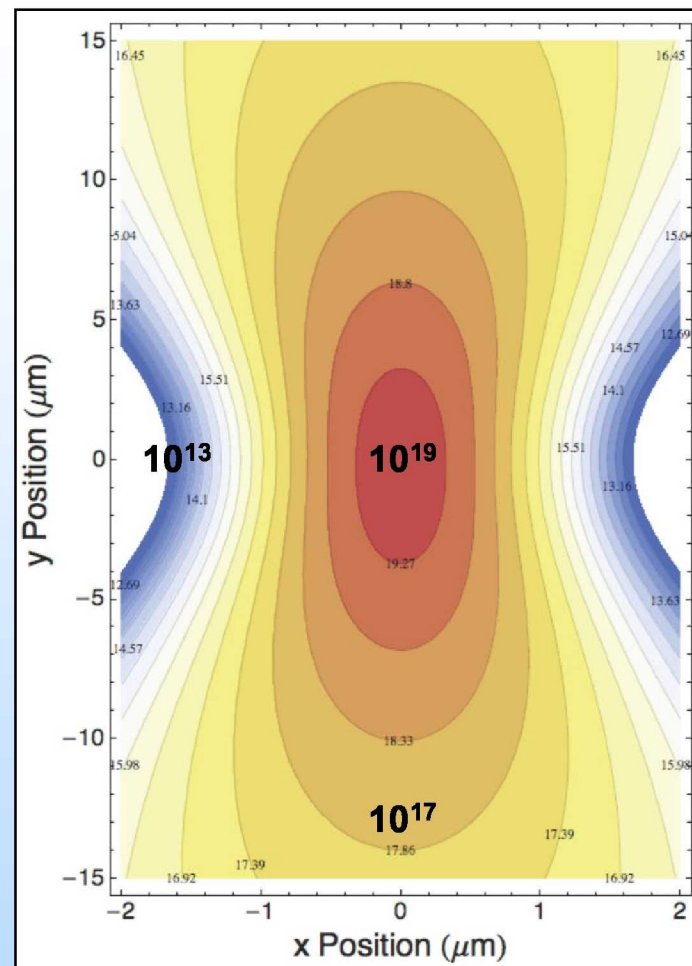


NRL 2-photon setup

Six 2.9 mm coaxial connectors



Custom High-Speed Package



Units are (e-h pair/cm³)

1260 nm TPA Electron-hole pair density contour

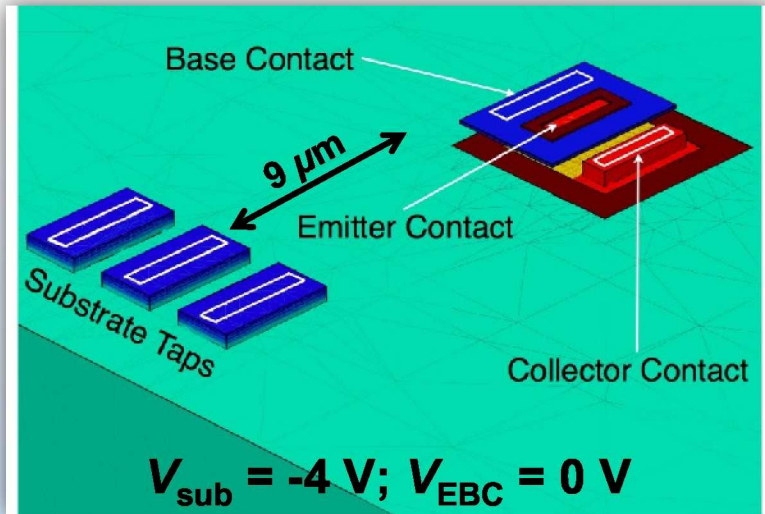
Electron-hole pair charge packet positioned at DUT in all three dimensions

J. A. Pellish et al., *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

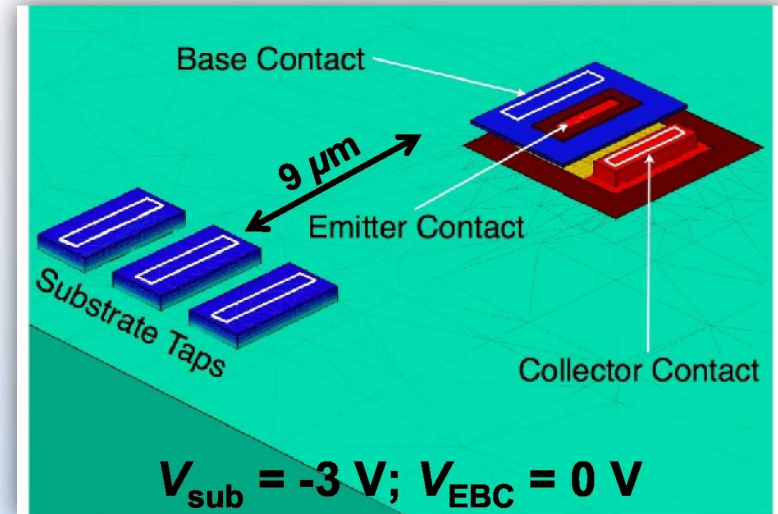
To be presented by Jonathan A. Pellish at the 2009 MURI Review, Vanderbilt University, Nashville, TN on 11/June/2009 and published on <http://radhome.gsfc.nasa.gov/>, <http://www.nepp.gov/>, and <http://www.isde.vanderbilt.edu/>

Bias Conditions of Interest

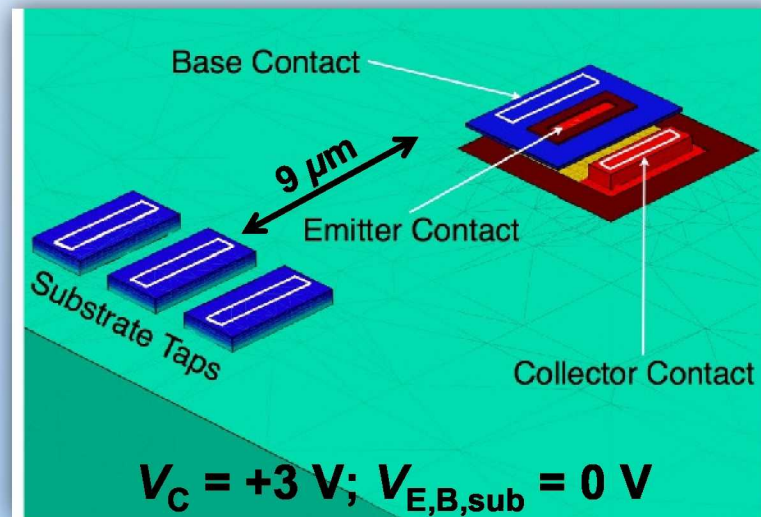
CASE 1



CASE 3



CASE 2



- 3-D TCAD
- Rendering from GDSII of actual DUTs

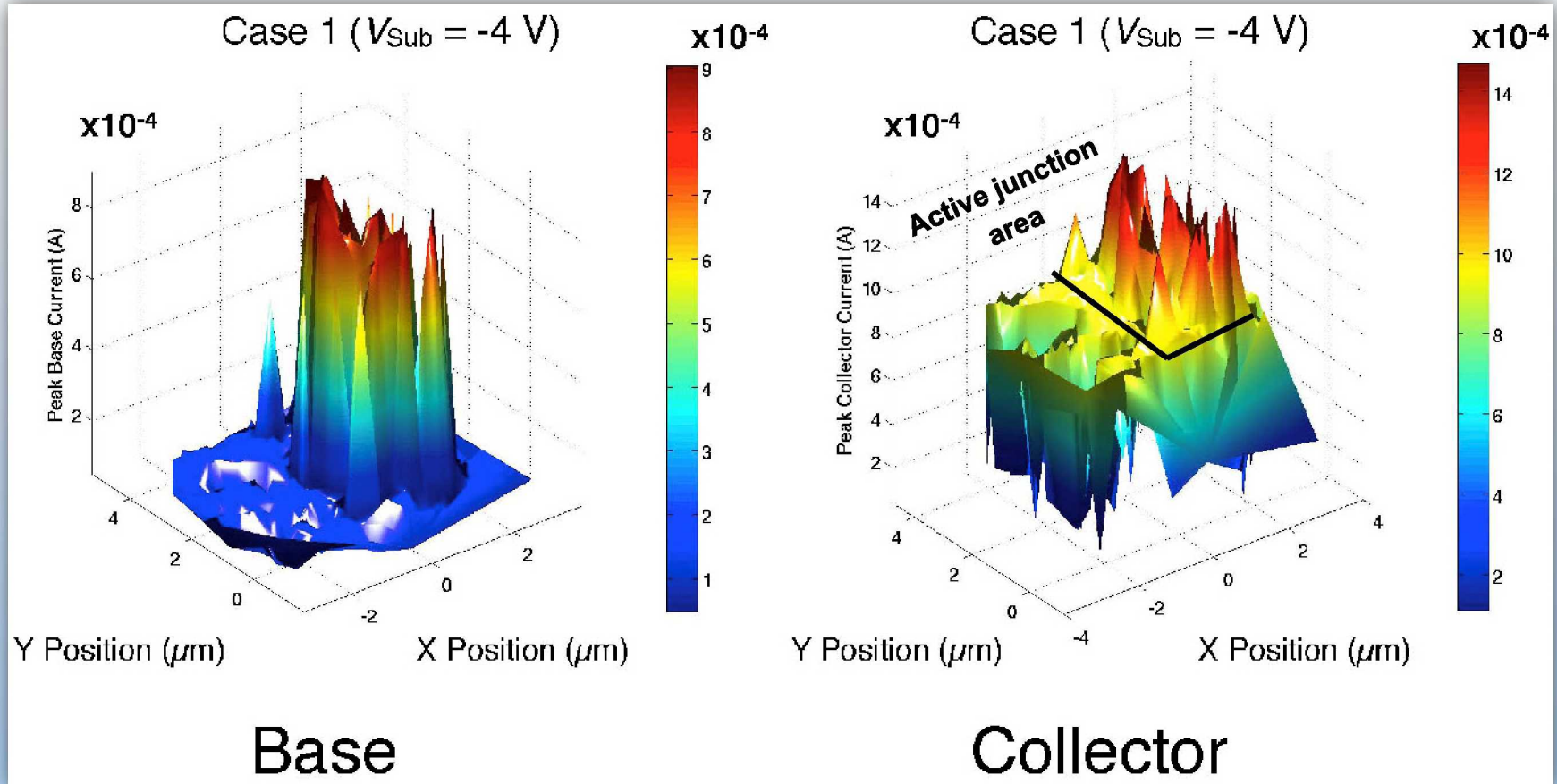


Heavy Ion Microbeam Transients

36 MeV ^{36}O Microbeam Data: Case 1



Peak Current Magnitude

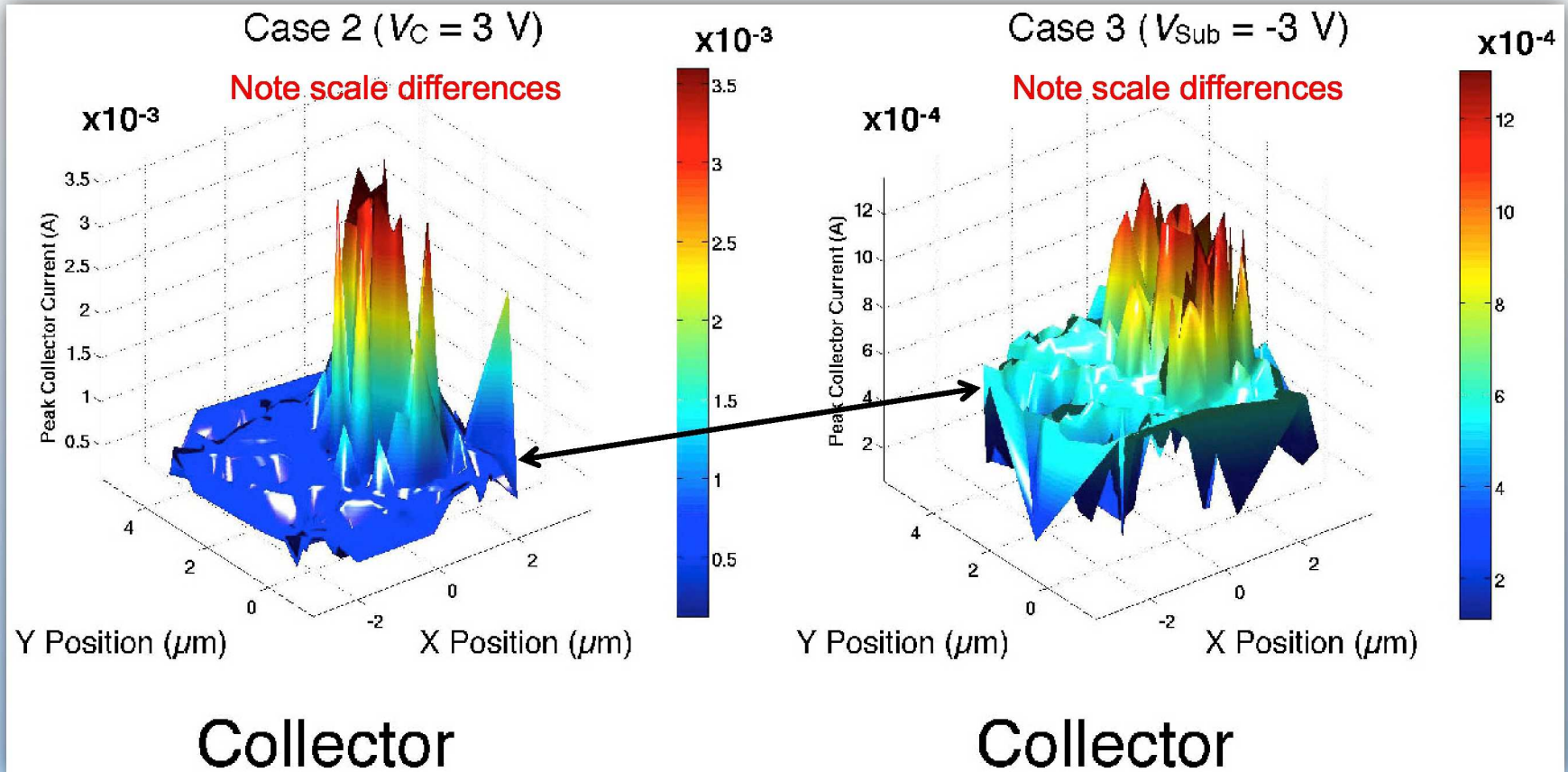


- Base terminal images base-collector junction
- Collector terminal images base-collector junction and subcollector

36 MeV ^{36}O Microbeam Data: Cases 2 & 3



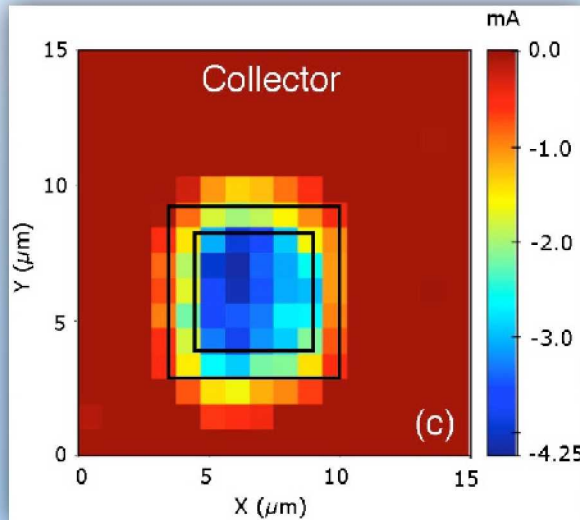
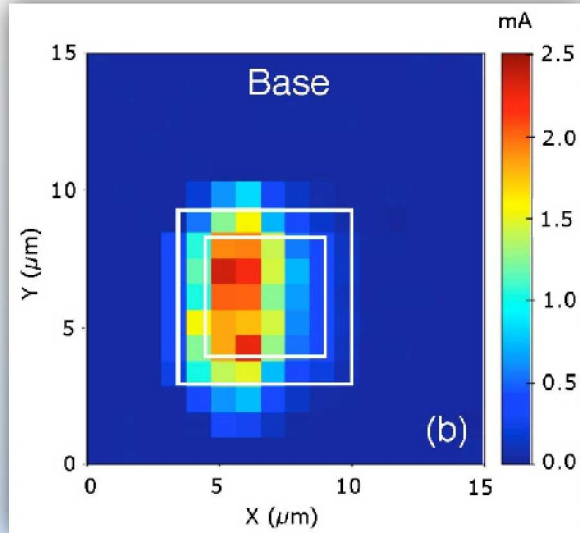
Peak Current Magnitude



- Significant current magnitude increase for $V_c = +3\text{ V}$
- Observed in two-photon pulsed laser testing too

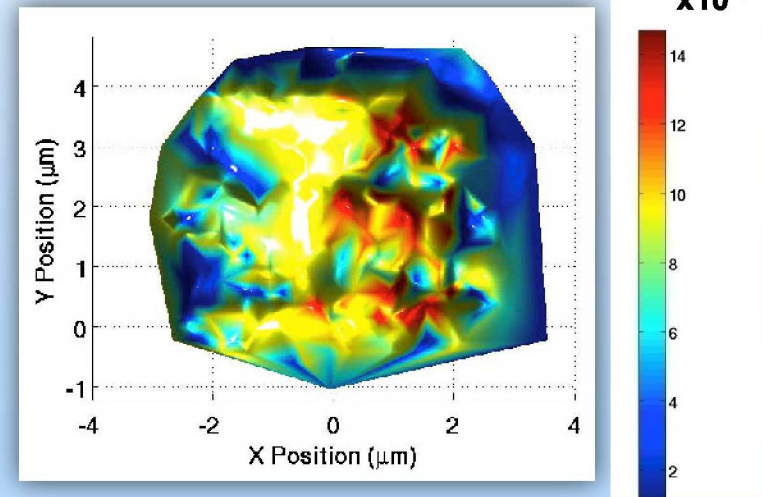
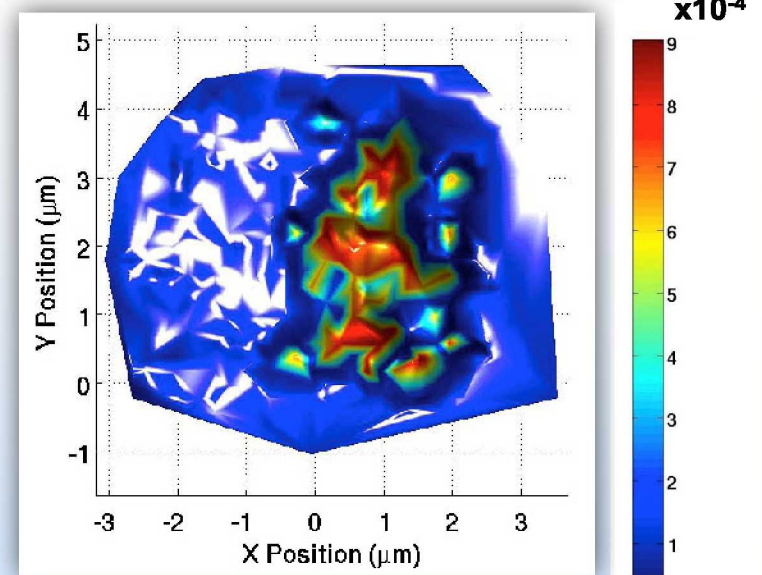
TPA Pulsed Laser vs. Microbeam

J. A. Pellish et al., *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.



TPA Pulsed Laser

**Both data
sets for
CASE 1
($V_{\text{sub}} = -4 \text{ V}$)**

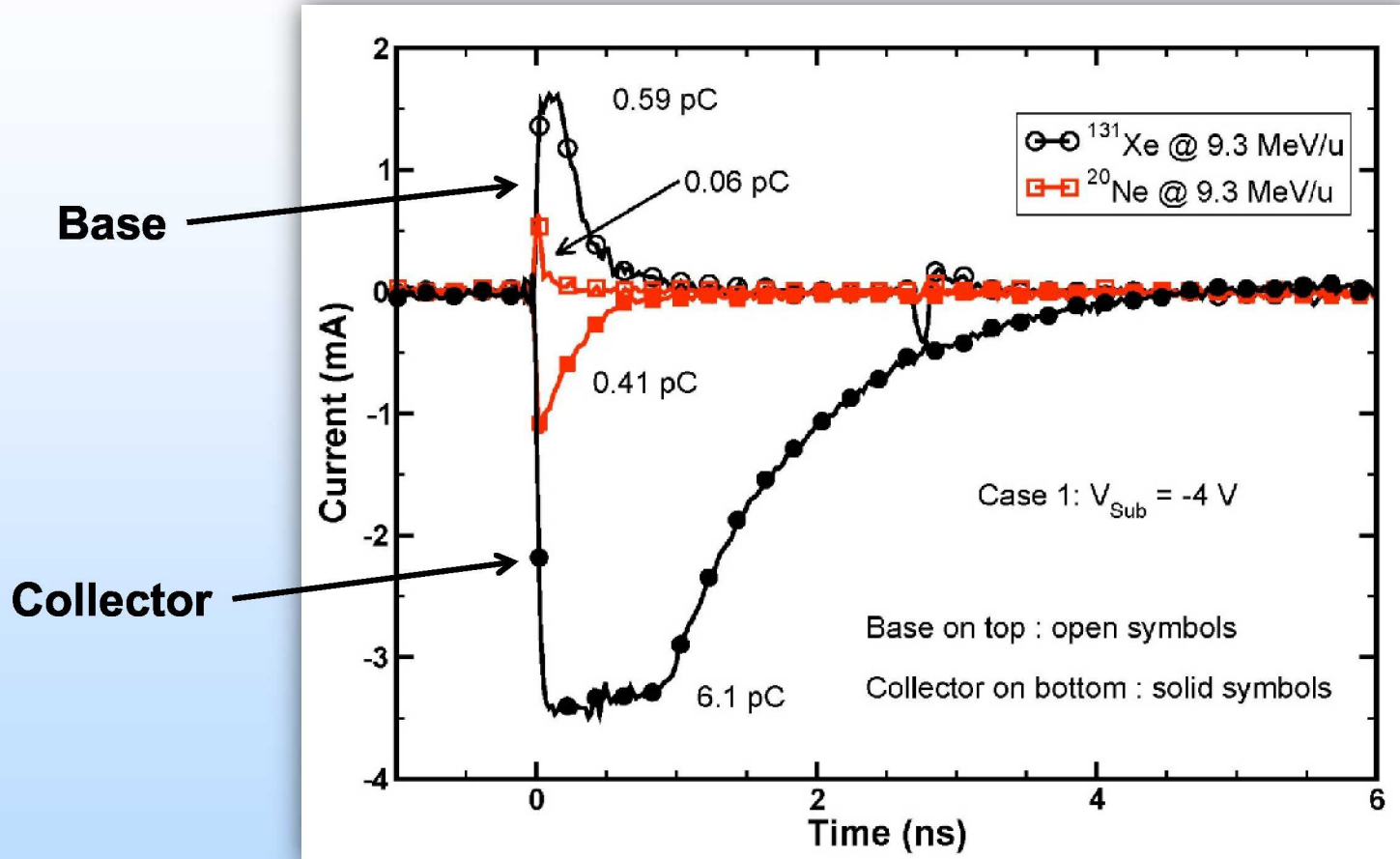


Microbeam



Heavy Ion Broadbeam Transients

JYFL Broadbeam Transients

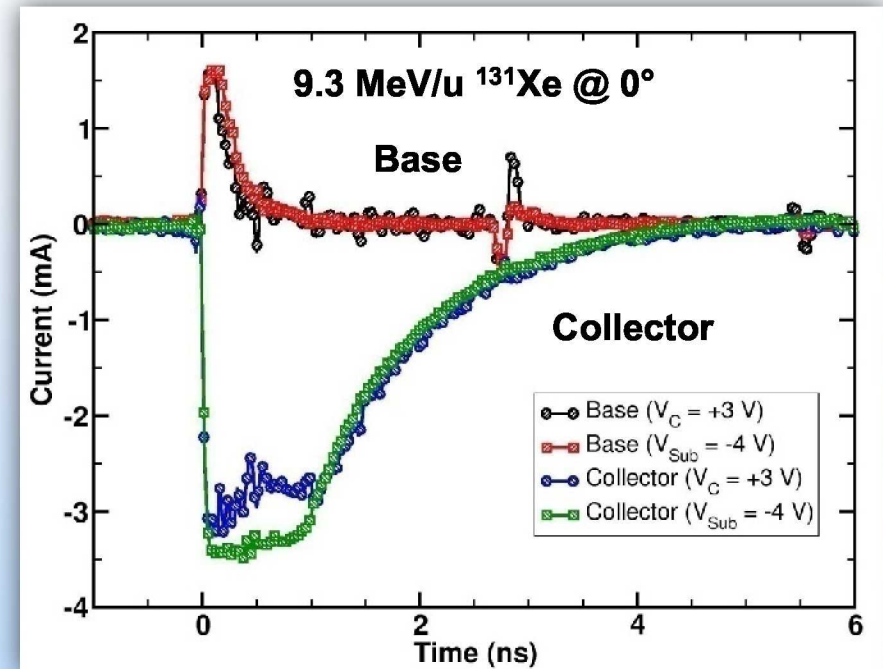
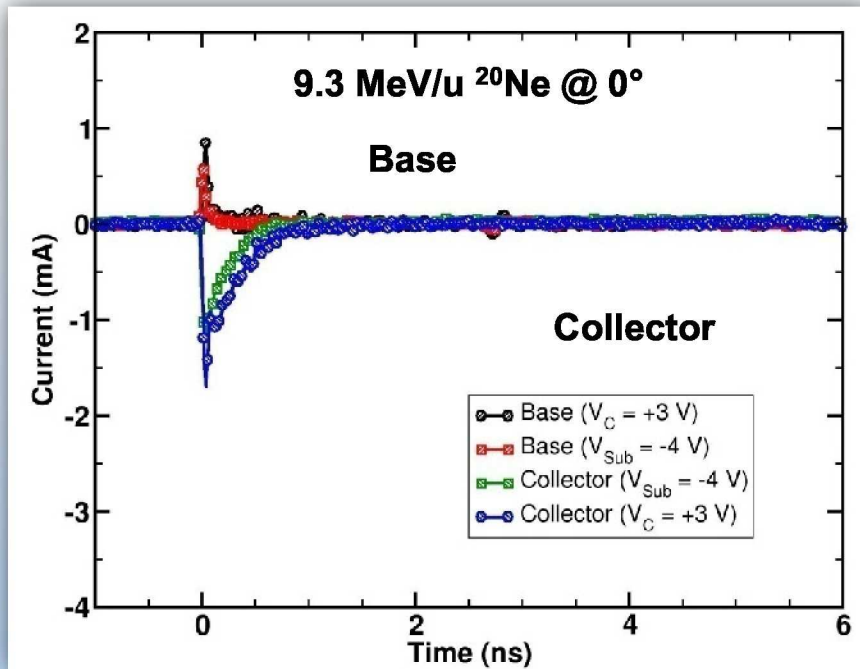


- Typical events observed from events somewhere within active region
- Position inferred using SNL microbeam data

JYFL Broadbeam Transients



Maximum amplitude transients as a function of bias

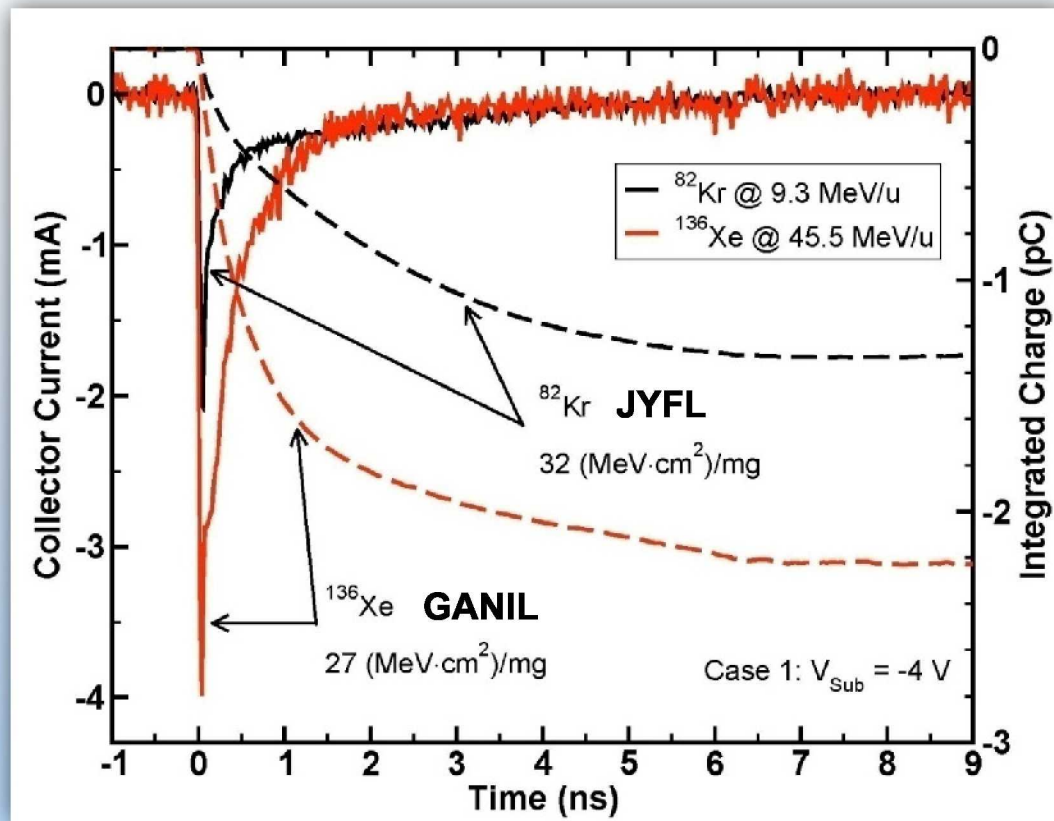


- Saturation of collector current transient with highly ionizing particle
- Some bias dependence, but masked by random hit location

JYFL vs. GANIL Broadbeam Transients



Ion
Range



Recombination

- Similar LET values produce different transient responses
- Trend holds for average of all transients for each LET



Path Forward

- **Attempt to uncover reason for increase in collector current for $V_C = +3$ V bias condition**
 - Impact ionization, bias scheme or other positive feedback
- **Uncover role of ion range and recombination mechanisms in lightly-doped substrates**
 - GANIL 45.5 MeV/u ^{136}Xe vs. JYFL 9.3 MeV/u ^{82}Kr
- **Build new devices and circuits with matching networks to provide appropriate impedances**
 - Both “looking in” and “looking out”

Summary



- **Time-resolved ion beam induced charge reveals heavy ion response of IBM 5AM SiGe HBT**
 - Position correlation
 - Unique response for different bias schemes
 - Similarities to TPA pulsed-laser data
- **Heavy ion broadbeam transients provide more realistic device response**
 - Feedback using microbeam data
 - Overcome existing issues of LET and ion range with microbeam
- **Both micro- and broadbeam data sets yield valuable input for TCAD simulations**
 - Uncover detailed mechanisms for SiGe HBTs and other devices fabricated on lightly-doped substrates
 - What type of device transient constitutes a circuit effect?